

**HIGH CAPACITY DIGITAL DATA STORAGE BY TRANSMISSION OF
RADIANT ENERGY THROUGH ARRAYS OF SMALL DIAMETER HOLES**

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a conversion of Provisional Application, U.S. Serial No. 60/242,042 filed on October 20, 2000.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to digital data storage, and more particularly, to high capacity digital data storage by transmission of radiant energy through arrays of small diameter holes.

2. Prior Art

Compact Discs (CD's) and Digital Versatile Disks (DVD's) have been developed to increase the amount of data that can be stored on a storage medium. These types of storage medium have data written on them in the form of pits and lands that are written and read with lasers along a track. Generally, the track is helical in shape and each pass of the track is separated from adjacent passes of the track by a track pitch. A standard single sided CD can store approximately 800 Megabytes of data, while a double-sided CD can store 1600 Megabytes of data. A DVD, has a track pitch of about .74 microns and a single side/single layer DVD can store about 4.4 Gigabytes of data, which is roughly

equivalent to about 2 hours of movie playing time.

Therefore, movies and other types of digital content cannot fit on a CD and can very easily be too large to even fit on a DVD. Furthermore, with the advent of certain technologies and business plans for the distribution of "content", it may be advantageous to store a library of digital content, such as movies, on a single removable storage medium. Current CD's and DVD's cannot be used for such purposes.

SUMMARY OF THE INVENTION

Therefore it is an object of the present invention to provide a data storage medium having a higher storage density than the storage mediums of the prior art.

Accordingly, a storage media for storage of data thereon is provided. The storage media comprises: a first layer, the first layer being substantially transparent to a predetermined radiant energy used for reading the data; and a second layer formed on the first layer and being substantially opaque to the radiant energy, the second layer having a pattern comprising a plurality of holes, each of the holes having a largest dimension which is greater than a wavelength of the radiant energy, the data being stored as the presence or absence of a hole in the pattern.

Preferably, the first layer is polycarbonate and the second layer is a metalization coating. The metalization coating is preferably aluminum.

Preferably, the plurality of holes are circular and the largest dimension is a diameter of the circular holes. The

diameter of the holes is preferably in the range of about 30 to 100 nanometers with a distance between successive holes preferably being in a range of about 30 to 100 nanometers.

The pattern preferably comprises the plurality of holes arranged along a helix beginning near a center of the storage media and extending spirally outward, each successive pass of the helix being separated from a previous pass of the helix by a track pitch. The track pitch is preferably about 100 nanometers.

Preferably, the plurality of holes are circular and the largest dimension is a diameter of the circular holes, the diameter of the holes being about 50 nanometers, a distance between successive holes being about 100 nanometers, and the track pitch being about 100 nanometers. Alternatively, the diameter of the holes being about 30 nanometers, a distance between successive holes is about 60 nanometers, and the track pitch being about 100 nanometers.

Preferably, the storage media further comprises a third layer, the third layer being disposed on the second layer and being substantially transparent to the radiant energy. The third layer is preferably acrylic.

The storage media is preferably circular in shape and has a data storage area having an inner diameter of about 25 millimeters and an outer diameter of about 115 millimeters.

Also provided is a method for making the storage media having data stored thereon. The method comprises: forming a first layer, the first layer being substantially transparent to a predetermined first radiant energy used for reading the data;

forming a second layer on the first layer which is substantially opaque to the first radiant energy; and forming a pattern comprising a plurality of holes in the second layer, each of the holes having a largest dimension which is greater than a wavelength of the first radiant energy, the data being stored as the presence or absence of a hole in the pattern.

Preferably, the first layer is polycarbonate formed by a casting process. The second layer is preferably a metalization coating formed by sputtering the metalization on the first layer.

The pattern of the plurality of holes are preferably arranged along a helix beginning near a center of the storage media and extending spirally outward, each successive pass of the helix being separated from a previous pass of the helix by a track pitch.

The method for making the storage media preferably further comprising forming a third layer on the second layer, the third layer being substantially transparent to the first radiant energy.

The plurality of holes are preferably formed by x-ray lithography, by melting material in the second layer, or by ablating material in the second layer. Preferably, the plurality of holes are formed by a second radiant energy having a wavelength less than a wavelength of the first radiant energy. The second radiant energy is preferably selected from a group consisting of ultraviolet light, x-rays, and electron beams.

Further provided is an apparatus for reading the storage media. The apparatus comprises: a radiant energy source

having an output of radiant energy directed towards the plurality of data holes; and a plurality of detectors for detecting the radiant energy diffusing from the plurality of data holes.

The radiant energy source is preferably a blue laser diode or an ultraviolet laser diode. The radiant light source preferably has a wavelength in the range of about 50 nanometers to 450 nanometers and most preferably a wavelength of about 410 nanometers.

The detectors are preferably photodetectors. The photodetectors are preferably formed of a wide bandgap material, such as silicon carbide, gallium arsenide, gallium nitride, aluminum nitride, zinc selenide, gallium nitride/aluminum nitride alloy, aluminum nitride/silicon carbide alloy and aluminum gallium nitride/gallium nitride.

The apparatus preferably further comprises a mask positioned between the storage media and the detectors for reducing interference from the radiant energy diffusing through unintended data holes. The mask preferably comprises a material having a pattern of mask holes arranged to restrict the number of data holes observed by a single detector. Preferably, the mask holes are rectangular in shape and have a smaller side dimension approximately equal to the largest dimension of the data holes.

Preferably, the radiant energy source is positioned on the side of the storage media having the first layer and is directed towards the detectors that are positioned on the side of the storage media opposite the first layer.

Still yet provided is a method for reading the storage

media. The method comprises: directing radiant energy from a radiant energy source towards the plurality of data holes; and detecting the radiant energy diffusing from the data holes with a plurality of detectors.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the apparatus and methods of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

Figure 1 illustrates a side view of a representative high capacity digital storage medium in the form of a polycarbonate disk with an opaque layer containing the data holes and a protective coating.

Figure 2 illustrates an enlarged top view of a small portion of the disk of Figure 1 showing two adjacent track segments.

Figure 3 illustrates a side view of a portion of a disk such as the one shown in Figure 1 with an array of photodetectors on one side of the disk and a light source on the other side of the disk.

Figure 4 illustrates a top view of the arrangement shown in Figure 3.

Figure 5 illustrates a view of portions of one form of a masking arrangement.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In summary, the present invention is a storage media, and a device and method for storing and reading large amounts of digital data using an array of holes that transmit radiant energy whose wavelength is less than the diameter of the holes. Data is stored on low-cost media by melting or ablating material to form the holes using a light, such as ultraviolet, x-ray or electron beams, with a wavelength shorter than the light used to read back the data. To read the data, intense light is shined on one side of the media as an array of sensitive light detectors on the other side of the media which record and differentiate among the small amounts of light received.

Referring now to Figures 1 and 2 (not to scale), there is shown a preferred implementation of the storage media of the present invention, generally referred to by reference numeral 100. The storage media 100 is preferably a thin, transparent plastic disk approximately 120 millimeters in diameter, about the size of a conventional CD. Thus, storage media 100 is preferably circular in shape and has a data storage area having an inner diameter of about 25 millimeters and an outer diameter of about 115 millimeters.

The storage media comprises a first layer 102. The first layer 102 is substantially transparent to a predetermined radiant energy used for reading the data stored on the storage media 100. Since, as will be discussed below, the preferred radiant energy source is a light source having a wavelength between 50 and 450 nanometers, the first layer is preferably fabricated from a rigid polycarbonate layer 14, which is substantially transparent to such wavelength light. The polycarbonate first layer 102 can be fabricated by any methods

known in the art, such as by casting.

The storage media 100 also includes a second layer 104 formed on the first layer 102. The second layer 104 is substantially opaque to the radiant energy used to read the data stored on the storage media 100. Using the preferred light source discussed above, the second layer 104 is preferably metallic, such as aluminum. The metallic second layer 104 is preferably formed on the first layer 102 by a metalization process such as sputtering. Such processes are well known in the art. The second layer preferably has a thickness that is thick enough to be opaque to the radiant energy used to read the data from the storage media. Depending on the type of material, this thickness can be on the order of 50 to 250 nanometers, however, it may be more or less without departing from the scope or spirit of the present invention.

The second layer 104 has a pattern 106 comprising a plurality of holes 108 (alternatively referred to as "data holes"). Each of the holes 108 have a largest dimension which is greater than a wavelength of the radiant energy used to read the data. The data is stored on the storage media 100 as the presence or absence of a hole 108 in the pattern 106. The plurality of holes 108 are preferably circular where the largest dimension is a diameter of the circular holes 108. Those skilled in the art will appreciate that other shape holes 108 are possible without departing from the scope or spirit of the invention. Furthermore, those skilled in the art will appreciate that the formation of very small diameter circular holes results in holes that are substantially circular but which may deviate somewhat from a circular shape. The use of the term "circular" is meant to include such deviations.

The circular holes 108 preferably have a diameter in a range of about 30 to 100 nanometers (nm), more preferably of about 50 nanometers. The distance (S) between successive holes is preferably a hole diameter apart, or in a range of about 30 to 100 nanometers. Similar to the pattern of pits and lands on a conventional CD and DVD, the pattern 106 of holes 108 are preferably arranged along a helix track 110 beginning near a center of the storage media 100 and extending spirally outward. Each successive pass of the helix track is separated from a previous pass of the helix by a track pitch (P). Figure 2 illustrates two successive passes 110, 112 of the helix track 110. Figure 2 approximates the passes 110, 112 as being linear for clarification purposes. In the case where the diameter of the holes 108 is 50 nanometers, the track pitch is preferably 100 nanometers or twice the diameter of the holes 108. The pattern 106 of holes 108 is formed in the second layer 104 by methods known in the art such as by conventional x-ray lithography as is known in the fabrication of integrated circuits. As discussed above, data is stored on the storage media 100 as the presence or absence of a hole 108 in the overall pattern 106.

The storage media 100 preferably further has a third layer 116 formed on the second layer 104, which acts as a protective coating for the pattern 106 of holes 108. The third layer 116, like the first layer 102, is substantially transparent to the radiant energy used to read the data from the storage media 100. The third layer 116 is preferably acrylic and is deposited on the second layer 104 by methods known in the art, such as by spraying or chemical vapor deposition depending on the type of material and thickness desired.

The storage media 100 of the present invention

preferably has a size similar to a standard CD, namely having a 120 millimeter diameter disk and having 50 nm diameter holes spaced 100 nm center to center (S) as a helix with a track pitch (P) of 100 nm. This helix has a minimum diameter of 25 mm and an outer diameter of 115 mm. Thus, the total length of the helix is about 99,000 meters, and may contain up to $1E^{12}$ (1,000,000,000,000) holes or store up to 125 gigabytes of data. Similarly, using holes that are 30 nm in diameter, with a spacing (S) of 60 nm permits storage of up to 350 gigabytes of data. In the case of a 350 gigabyte capacity disk, the actual capacity may be significantly less when the data is encoded with error correcting codes and alignment rings or holes which are included to facilitate tracking a helical track of holes.

Referring now to Figures 3-5, there is illustrated a schematic representation of an apparatus for reading the data stored on the storage media 100 of the present invention, generally referred to by reference numeral 200. Conventional components of such a device are well known in the art and are therefore not discussed for the sake of brevity. Such components include, but are not limited to means for retaining the storage media, such as a platter; means for spinning the platter, such as a servo motor; and circuit means for tracking the holes 108, processing the stored data, and producing a useful result, such as to output the data to a video monitor in a desired format.

Figure 3 illustrates the apparatus 200 and a side view of the storage media 100 of Figure 1 oriented therein. The apparatus 200 includes a radiant energy source 202 having an output of radiant energy directed towards the plurality of data holes 108. Radiant energy source 202 is preferably a light source such as a blue or UV laser diode, such as those

manufactured by Cree, Inc. of Durham, North Carolina, USA. Light source 204 preferably operates at 3mW and produces an intense blue light at about 410nm. However, it will be appreciated that the light source is preferably in the deep UV to blue range of about 50nm to 450nm in wavelength. It should also be appreciated that while radiant energy having wavelengths in this range are preferred, radiant energy below (e.g., x-rays) and above this band may also be used.

The light source 202 preferably takes the form of a solid-state light emitting diode or laser diode, formed from a wide bandgap material such as silicon carbide. Other wide bandgap materials include gallium arsenide, gallium nitride, aluminum nitride, zinc selenide, gallium nitride/aluminum nitride alloy, aluminum nitride/silicon carbide alloy and aluminum gallium nitride/gallium nitride heterojunctions, which, as known in the art, will produce light at a wavelength that is determined primarily by the bandgap of the semiconductor material. However, silicon carbide detectors are favored because they have the advantages of sensitivity that peaks in the range of deep blue and ultraviolet, extremely low dark current so that extremely small light levels can be detected, and relatively low fabrication costs.

Apparatus 200 also includes an array of detectors 204 arranged on an opposite side of the disk from the radiant energy source 202. The plurality of detectors 204 are preferably photodetectors and detect the radiant energy from the radiant energy source 202 diffusing from the plurality of data holes. The radiant energy source 202 is preferably positioned on the side of the storage media 100 having the first layer 102 and is directed towards the detectors 204 that are positioned on the

side of the storage media 100 opposite the first layer 102 (e.g., proximate to the second and third layers 104, 116).

When used with a radiant energy source 204 in the form of a light source 204, the discrete photodetectors 204 of the photodetector array are sensitive to light at the wavelength of the light source 204. In a preferred implementation, photodetectors 204 take the form of model no. CD-260-1-00-D silicon carbide ultraviolet photodetector chips manufactured by Cree, Inc. of Durham, North Carolina, USA. These photodetectors have extraordinary responsivity to light in a band including the wavelength of the light source 204 and have exceptionally low dark current. Further details for the manner in which photodetectors 204 are preferably arranged is shown in the top view of Figure 4.

Likewise, photodetectors used in accordance with the invention are preferably solid-state devices such as the mentioned Cree, Inc. silicon carbide photodetectors, where the responsivity curve of the photodetector matches the wavelength of the light output by the light source 204. Solid state photodetectors may be formed to match the light source from various wide bandgap semiconductor materials, including silicon carbide and the others mentioned above.

To read the data stored on the storage media 100, the storage media 100, in the form of a disk, is slowly spun while the source of radiant energy 202, for example, the blue or UV laser diode, is preferably focused into about a 1 micrometer diameter area on one side of the storage media disk 100 while the array of photodetectors 204 on the other side of the storage media disk 100 sense light passing through and diffusing from the holes 108 formed on the storage media 100.

The detectors 204 may be arrayed in a brick-like pattern as illustrated in Figure 4. The brick array of detectors 204 may have redundant detector elements so that not all detector elements need to be operational. Thus, even flawed detector arrays are usable so that fabrication costs will be lessened by excellent yields.

Referring now to Figure 5, a masking means is illustrated, generally referred to by reference numeral 300. The masking means 300 masks the detectors 204 to restrict the number of holes 108 observed by a single detector 204. The masking means 300 is carried by a servo mechanism of the tracking system (not shown) used to track the holes 108. Masking means 300 includes a mask body 302 with masking openings 304 preferably having a diameter corresponding to the diameter of holes 108 in the second layer 104, for example, 50 nm. Mask body 302 is attached to the servo mechanism by a mounting member 306. In a preferred implementation of the apparatus 200 for reading the data stored on the storage media 100, individual detectors 204 are masked with masking openings in the form of rectangles such that the sides of the rectangles approximate the diameters of the holes 108 in the media. The mask body 302 is preferably sufficiently thick so that the masking openings 304 act both as apertures and tunnels in reducing interference from light flowing through nearby data holes 108. The mask body 302 on the detector array is preferably also held very close to the surface of the storage media 100 to minimize crosstalk between neighboring holes. In an alternate implementation, a lens (not shown) positioned between the array of detectors 204 and the mask body 302 avoids the need to closely position the array against the mask body while still limiting crosstalk of light between adjacent holes.

The use of strong blue, deep blue and ultraviolet laser diodes and corresponding high-sensitivity photoelectric sensors makes possible this new type of optical storage medium based upon the weak transmission of light through extremely tiny holes (or blocked by extremely tiny objects). By nature of the substrates used to produce photoelectric sensors, sensors for very short wavelengths have extraordinarily small dark currents so that with proper amplification, extremely small quantities of light can be measured without requiring cooling. Furthermore, because sensors can be fabricated by an inexpensive process, arrays of these sensors can be made reliably for a very low per-pixel cost. Furthermore, by fabrication of arrays of these sensors on a single substrate, perhaps several millimeters square, following the path of the holes on the storage media can be accomplished by completely electronic means (except for a relatively imprecise mechanical motor and gearing to slowly step the small array across the radius of the storage media).

It is also possible to use the array of sensors to read multiple tracks of the helix simultaneously, allowing a slower rotation of the storage media or higher data rates than are currently possible with conventional media such as a CD. For example, simultaneous reading of ten tracks would allow the storage media to move at a speed of 30 mm/sec by turning at a rate of about 5 to 30 rpm.

Those skilled in the art will appreciate that the high capacity digital data storage media of the present invention allows low cost distribution of data. For example a 125 gigabyte disk may store about 100 movies that can be decompressed and played with VHS quality, or it may store the music from the 1000 CD's, again using typical audio compression techniques such as

MPEG-3 or AAC. Use of higher compression techniques would permit the storage of even more movies and/or CD's on such a disk. This low-cost storage media presents an opportunity for new and advantageous business models for the mass distribution of movies and/or music to consumers.

While there has been shown and described what is considered to be preferred embodiments of the invention, it will, of course, be understood that various modifications and changes in form or detail could readily be made without departing from the spirit of the invention. It is therefore intended that the invention be not limited to the exact forms described and illustrated, but should be constructed to cover all modifications that may fall within the scope of the appended claims.